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A SIMULATION OF ROTOR-STATOR INTERACTION USING THE EULER EQUATIONS AND PATCHED GRIDS

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SUMMARY

An unsteady Euler code to study rotor-stator interaction problems has been developed. The code uses patched grids that move relative to each other to simulate the motion of the rotor airfoils with respect to the stator airfoils. The Osher integration scheme is used in conjunction with an implicit relaxation approach. The scheme is second-order accurate in space and time, and is also TVD in each spatial direction.

The numerical results were found to be periodic in time, thus demonstrating the capability of the integration and zonal schemes in simulating periodic time-dependent flow. The pressure contours obtained are almost oscillation-free because of the TVD nature of the scheme. They are also continuous across the moving patch boundary, and indicate the quality of solutions possible with the current zonal boundary scheme. The contours depict a shock "buzz" phenomenon wherein the leading edge shock of the second-airfoil periodically attaches and detaches from the airfoil.

A new procedure has been developed to simulate flows about bodies that move relative to each other. This capability should prove to be very useful in the areas of rotor-stator interaction, propeller-nacelle interaction, helicopter rotor-fuselage·interaction, and many other related areas.

INTRODUCTION

A clear understanding of the aerodynamic processes associated with fluid flow through turbomachines is essential for the performance optimization of turbomachinery. There are several factors that make the numerical simulation of such flows extremely difficult. The unsteady nature of the flow, the complex geometries involved, the movement of some airfoils with respect to others, and the periodic transition of the flow from laminar to turbulent are some of the factors that contribute to the complexity of the problem. In this study, the two-dimensional supersonic flow past a generic rotor-stator configuration consisting of two circular arc airfoils is analyzed.

A finite-difference solution to the Euler equations requires the generation of a computational grid for the geometry of interest. The generation of a single grid for regions containing multiple bodies is not a simple task and is even more complicated when some of these multiple bodies move relative to each other. (In fact, in many cases it is impractical, if not impossible, to generate a single grid for the region of interest.) An alternative to the "single-grid" approach is the "patched-grid" approach. In the patched-grid approach, the calculation is performed on several grids that are patched together as in Fig. 1. An important consideration in calculations with patched grids is the accurate transfer of information from one grid to another. The finite-difference equations used to effect

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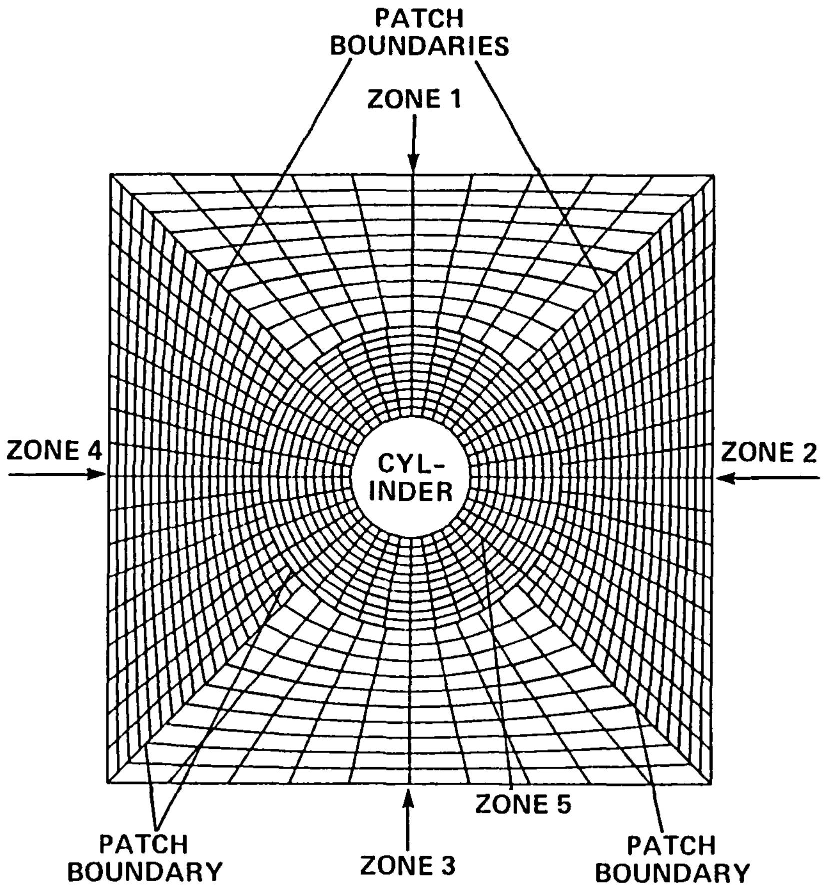

Fig. 1 An example of patched grids.

this information transfer must satisfy several requirements before they can be used effectively. Some of these requirements are listed below. The equations must be:

1) numerically stable,

2) spatially and temporally accurate,

3) conservative so that flow discontinuities can move from one grid to another without any distortion,

4) easily applicable in generalized coordinates.

Recent efforts in the use of multiple-grids for solving geometrically complex problems [1-3] indicate that performing calculations on patched-grids with the Euler equations is possible. However, the flexibility that they provide in treating complex topologies is obtained at the expense of programming simplicity.

References 1-3 deal with the treatment of patched-grids. In the patched-grid technique, the different "patches" or "zones" are separated by common boundaries called patch boundaries. The grid points on these patch boundaries need to be treated with care so that the requirements mentioned earlier (numerical stability, accuracy, and conservation across patch

boundaries) are satisfied. A patch boundary condition that meets these requirements is developed in Refs. 1-3.

In Ref. 1, a conservative patch boundary condition is developed for explicit, first-order accurate integration schemes, and the Euler equations. This patch-boundary scheme is extended to implicit, second-order accurate integration schemes in Ref. 2. The feasibility of performing calculations on grids moving relative to each other is demonstrated in Ref. 2, and the equations necessary to maintain time accuracy (in addition to the usual requirement of spatial accuracy) at the patch boundary are also developed. Reference 3 gives the extension of the explicit patched-grid scheme to relaxation schemes (as opposed to the approximately factored implicit schemes used in Ref. 2). Preliminary results for the rotor-stator configuration used in this study are also presented in Ref. 3. However, the axial gap between the stator and rotor airfoils used in Ref. 3 is large and, hence, the interaction is weak. In this study, the axial gap is much smaller (20% of the chord length) and, hence, there is a much stronger interaction.

In the present study, the patched grid technique of Ref. 3 is used to simulate the flow associated with a simple rotor-stator configuration consisting of circular-arc airfoils. The unsteady Euler equations in two spatial dimensions are solved using an implicit relaxation procedure in conjunction with the Osher scheme [3-5]. The results presented include pressure contours at different times and pressure variation with time at selected locations on the stator airfoil.

RESULTS

This section presents results obtained with the unsteady Euler equations for a simple rotor-stator configuration in which both the rotor and stator are circular arc airfoils. The axial gap between them is 20% of the chord length. The freestream Mach number is 1.5. The integration scheme used is the implicit Osher scheme. It is second-order accurate in space and time and is total variation diminishing (TVD) in each spatial direction.

Figure 2 shows the two-zone grid used to discretize the region of interest. The grid in zone 2 is stationary (as is the aft airfoil), and

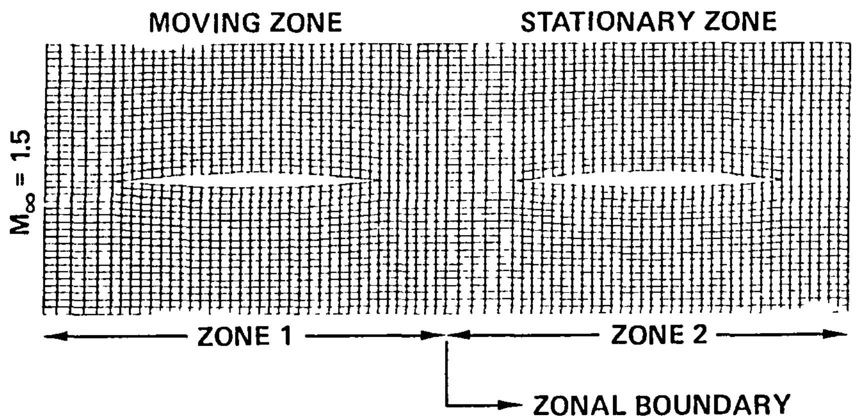

Fig. 2 Two-zone grid for the double airfoil-calculation.

the grid in zone 1 is fixed to the first airfoil which is moving vertically downward. Although the grid lines are continuous at the zonal boundary in Fig. 2, a discontinuity in these grid lines will develop as the first airfoil and zone 1 move downward. The zonal-boundary points of zone 1 will slip past the zonal-boundary points of zone 2.

Periodic boundary conditions are imposed on the upper and lower boundaries of both zones. Freestream conditions are imposed on the left boundary of zone 1 and supersonic exit boundary conditions are imposed on the right boundary of zone 2. The implicit, zonal boundary condition of Ref. 3 is used at the boundary separating the two zones. Details of the inviscid surface boundary condition used can be found in Ref. 4.

The calculation was initially performed with both airfoils stationary. After 50 integration steps, the first airfoil was given a downward velocity (the magnitude of the velocity corresponding to a Mach number of 0.1 with respect to freestream conditions) and the calculation was continued until the solution became periodic in time. The calculation was performed at a CFL number of approximately 2.0. At this CFL number, 250 integration steps were required for each cycle (one cycle corresponds to the motion of the upper boundary of zone 1 from its current position to the position occupied currently by the lower boundary of zone 1). Approximately three cycles were required to eliminate the initial transients and to establish a solution that is periodic in time.

Figures 3-8 show pressure contours at various positions of the forward airfoil (with respect to the aft airfoil) as it moves downward. These contours were obtained after the initial transients had subsided. Although the calculation was performed with only two airfoils, for the sake of clarity Figs. 3-8 depict four airfoils (information regarding the additional airfoils was obtained from the periodicity condition). Figure 3 shows contours at $t = 0.0$ (one cycle corresponds to $t = 1.0$). The downward motion of the forward airfoil results in an effective angle of attack which, in turn, results in an attached oblique shock on the lower side and a weak expansion fan on the upper side at the leading edge of the first airfoil. The interaction of this shock with the adjacent forward airfoil is clearly seen. A second weak attached shock is also evident at the

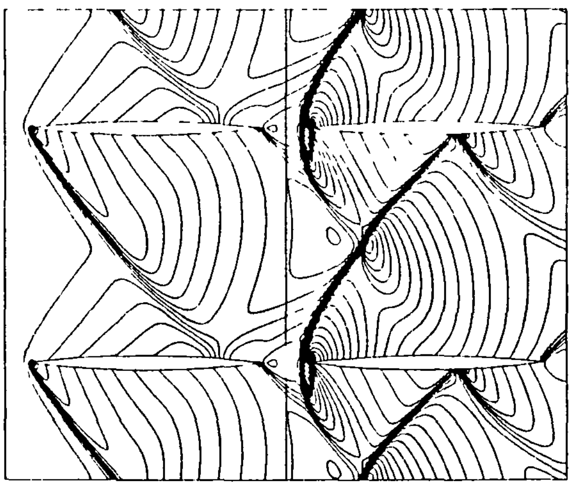

Fig. 3 Pressure contours at $t = 0.0$.

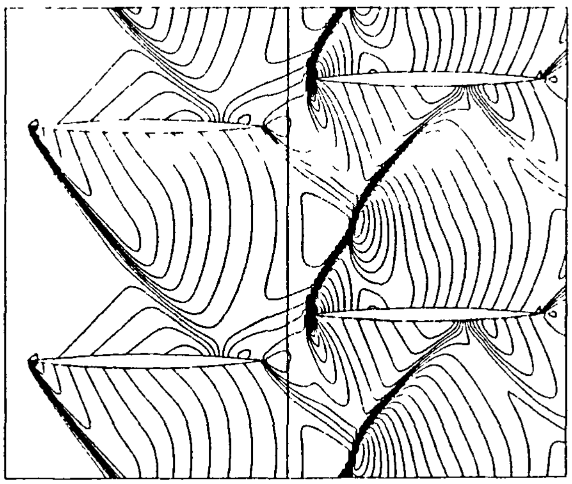

Fig. 4 Pressure contours at $t = 0.2$.

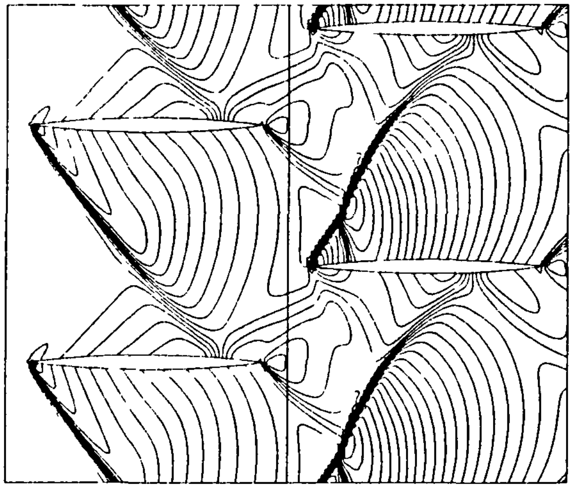

Fig. 5 Pressure contours at $t = 0.4$.

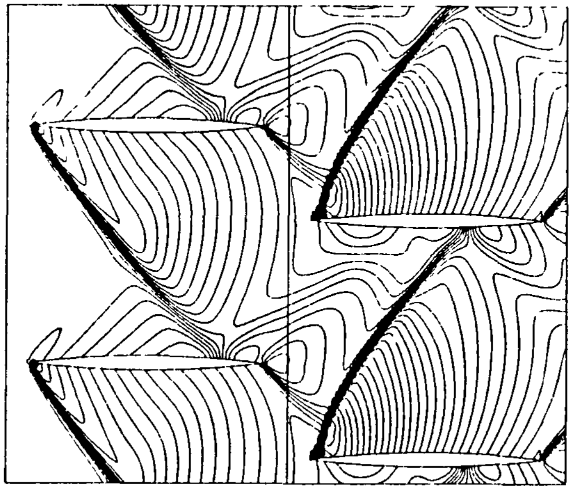

Fig. 6 Pressure contours at $t = 0.6$.

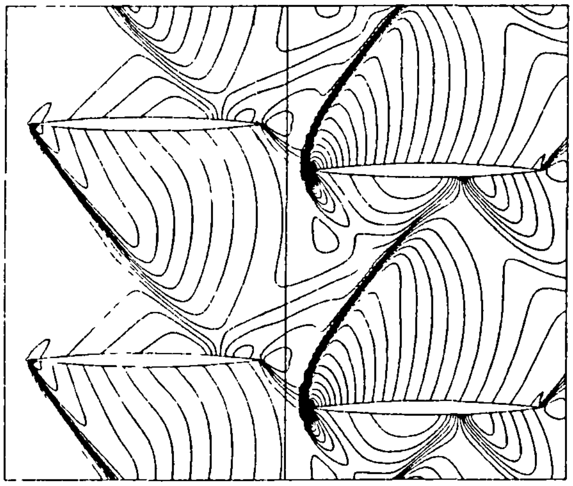

Fig. 7 Pressure contours at $t = 0.8$.

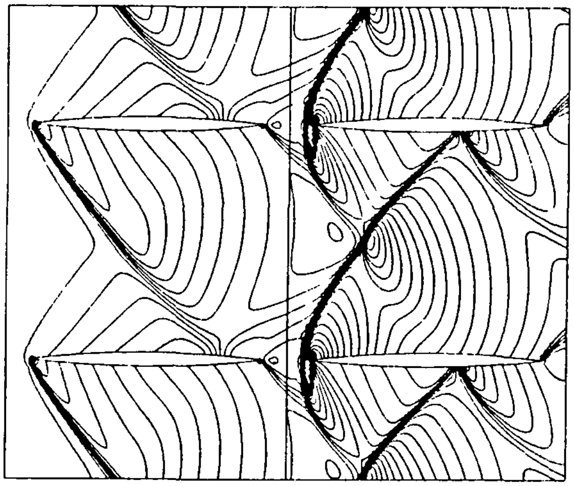

Fig. 8 Pressure contours at $t = 1.0$.

the trailing edge (lower side) of the forward airfoil. At the position $t = 0.0$, the leading edge shock associated with the second airfoil is detached. It is seen impinging on the surface of the adjacent second airfoil.

The interaction of the trailing edge shock of the first airfoil and the leading edge shock of the second airfoil is also clear from Fig. 3. This interaction area moves downward as the first airfoil moves downward. This in turn results in the leading edge shock of the second airfoil attaching and detaching periodically from the leading edge. Figures 4-8 depict this attachment/detachment process. In Fig. 4 the shock is beginning to reattach. In Fig. 5 it is a weak attached shock and in Fig. 6 it is a strong attached shock (beginning to detach again). It is completely detached in Fig. 7 and, finally, in Fig. 8 the contours are identical to those in Fig. 3 thus demonstrating the accuracy of the present technique in calculating periodic flows.

An important feature in Figs. 3-8 is that the contours are continuous, even slope continuous, across the zonal boundary. This high degree of continuity is because of the conservative nature of the zonal scheme, and the manner in which continuity of dependent variables is enforced across the zonal boundary [1-3]. Another interesting feature is that the captured shocks are almost oscillation-free. (The absence of large oscillations is because of the TVD nature of the integration scheme.)

Figure 9 shows the pressure variation with time at midchord on the lower surface of the aft airfoil. This pressure variation corresponds to the fourth and fifth cycles. Clearly, the pressure is periodic in time, thus demonstrating the capability of the integration and zonal boundary schemes in simulating periodic time-dependent flow. Figure 10 shows the surface pressure variation at midchord on the upper surface of the aft airfoil. The behavior seen in Fig. 10 is similar to that seen in Fig. 9 except for a phase shift and a difference in the mean value of the pressure.

One aspect of rotor-stator configurations that is not represented in the present results is the effect of the aft airfoil on the forward airfoil. The supersonic nature of the flow does not permit such an interaction. However, the zonal boundary conditions were implemented such that an interaction, if present, would be properly accounted for. The calculation of Ref. 6 with purely subsonic flow in the region of interest shows the capability of the zonal scheme in accurately simulating such an interaction.

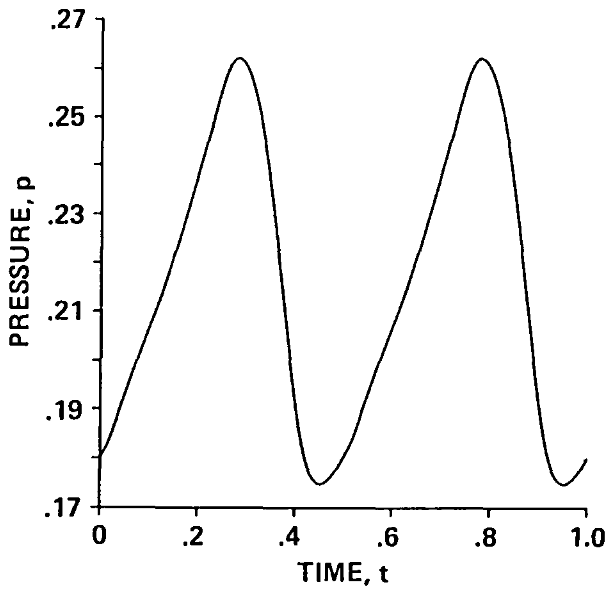

Fig. 9 Pressure history at midchord on the lower surface of the aft airfoil.

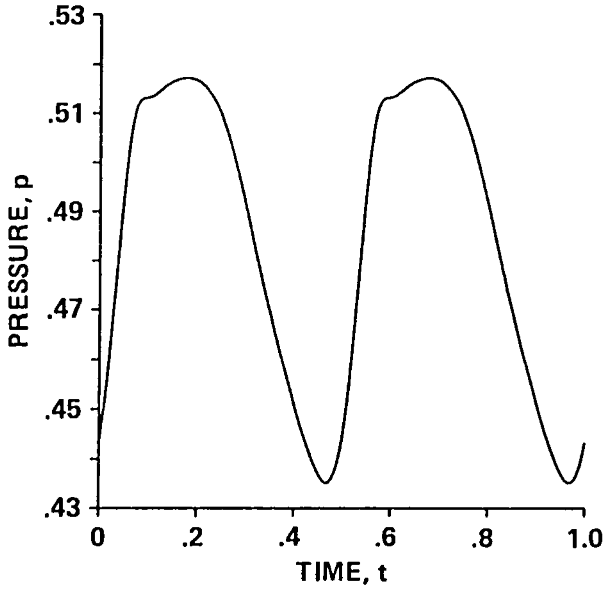

Fig. 10 Pressure history at midchord on the upper surface of the aft airfoil.

REFERENCES

[1] RAI, M. M.: "A conservative treatment of zonal boundaries for Euler equation calculations," AIAA Paper 84-0164 (1984).

[2] RAI, M. M.: "An implicit conservative zonal boundary scheme for Euler equation calculations," AIAA Paper 85-0488 (1985)

[3] RAI, M. M.: A relaxation approach to patched-grid calculations with the Euler equations," AIAA Paper 85-0295 (1985).

[4] CHAKRAVARTHY, S. R.: "Implicit upwind schemes without approximate factorization," AIAA Paper 84-0165 (1984).

[5] RAI, M. M., CHAKRAVARTHY, S. R.: "An implicit form for the Osher upwind scheme," AIAA Paper 84-0088 (1984)

[6] RAI, M. M.: "Navier-Stokes simulations of rotor-stator interaction using patched and overlaid grids," AIAA Paper 85-1519-CP (1985).

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16 Abstract

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